Overwintering ecology of two species of spider mites (Acari: Tetranychidae) on different host plants

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Abstract

The overwintering ecology of two species of spider mites was studied on three different host plants in central Wakayama Prefecture, southwestern Japan. Laboratory diapause-inducing experiments showed that populations of *Tetranychus urticae* on peas and chrysanthemums both had a very low inherent capacity for diapause, and the population on chrysanthemums continued development and reproduction throughout the winter. On the other hand, populations of *T. kanzawai* had a genetically strong diapause capacity, regardless of the host species on which they occurred. However, the proportion of field-induced diapause females was lower in the population occurring on *Akebia quinata*, an evergreen host that had ample fresh leaves throughout the winter, than the populations on peas and *Clerodendrum trichotomum*, a deciduous tree, the leaves of both of which deteriorated or defoliated in winter. The low incidence of diapause on *A. quinata* seemed due to weak diapause induction and/or earlier diapause termination in the plastic response to ample food conditions. On *A. quinata*, high proportions of eggs and immatures remained throughout the winter, suggesting that development and reproduction are possible throughout the winter in this area under ample food conditions.

Key words: Diapause, host quality, winter ecology, *Tetranychus kanzawai*, *Tetranychus urticae*

INTRODUCTION

Two species of spider mites, *Tetranychus kanzawai* and *T. urticae*, are widely distributed throughout Japan and both are serious pest species on a variety of agricultural crops. The two species have potentially wide host ranges (Gomi and Gotoh, 1996; Yano et al., 1998). *T. kanzawai* occurs not only on agricultural crops but also on wild plants growing far from crop fields, whereas *T. urticae* generally does not occur on non-cultivated plants, especially in warmer areas, although they can utilize the underground vegetation within and close to crop fields. Thus, although host utilization pattern differs slightly between the two species, both switch seasonally from one host to another in agricultural areas where the cultivation of crops is transient. For example, Morishita (1997) and Morishita and Takafuji (1999a) described inter-plant movement of the two species of mites in central Wakayama Prefecture with a mild winter climate. *T. kanzawai*, which occurs in the pea-watermelon cropping system in the area, also utilizes non-cultivated hosts in the border vegetation when crops are

not available. *T. urticae* also occurs in the cropping system but maintains its population on cultivated chrysanthemum during mid-summer when neither pea nor watermelon are available. These observations suggest that gene exchange will take place among populations occurring on different hosts.

The two mite species switch between diapause and non-diapause in response to seasonal cues such as short daylength and low temperature (see Veerman, 1985). *T. kanzawai* has a stronger tendency to diapause since most populations, except those in Okinawa, exhibit a very high incidence of diapause (Takafuji and Gotoh, 1999; Takafuji et al., 2001). On the other hand, *T. urticae* in Japan shows a clinal change in diapause incidence from nearly 0% to 100%, and populations in warmer areas have a very low diapause capacity (Takafuji et al., 1991).

Morishita and Takafuji (1999b) compared the diapause capacity of populations of *T. kanzawai* occurring on pea and two non-cultivated plants in central Wakayama Prefecture. The results showed that none of the populations exhibited such a high incidence of diapause as was found under laboratory-diapause-inducing conditions, where nearly

100% diapause was attained in the pea population. In the present study, we re-examined this field- and laboratory-induced incidence of diapause in three populations of *T. kanzawai* that occurred in the same area but on different hosts. We also studied the change in the abundance and stage structure of the two species throughout the winter.

The purpose of this study was to examine whether there is any difference in the phenotypic expression of and genetic capacity for diapause among populations occurring on different hosts that differ in phenology during winter. The former will elucidate whether host quality affects diapause expression and the population consequences during winter, and the latter whether there is any genetic divergence in diapause characteristics among populations occurring on different hosts. We also studied the same subjects for *T. urticae* occurring in the same area for comparison.

MATERIALS AND METHODS

Study sites and host plants. The field survey was conducted at Inami-cho (ca. 33°48'N, 135°14'E), central Wakayama Prefecture. We studied 3 populations of *T. kanzawai*, each occurring on cultivated pea and 2 non-cultivated hosts, *Clerodendrum trichotomum* Thunb. and *Akebia quinata* (Thunb.), and 2 populations of *T. urticae*, each occurring on pea and chrysanthemum. The pea field studied for *T. kanzawai* was different from that studied for *T. urticae*. The pea plants in the former were not well managed and therefore deteriorated earlier than those in the latter. All the host plants studied were located within a radius of 1.5 km.

C. trichotomum is a deciduous woody plant: leaves completely defoliate in late December though some small leaves remain on the tillers until mid-January and new leaves appear in mid-April. *A. quinata* is an evergreen host and new leaves sprout twice, in April–May and September, and favorable fresh leaves are amply available to the mites as food even during mid-winter. Peas are sown in late August, and grown until early February/mid-March depending on the variety. Chrysanthemums are grown from mid-July to February but mother stocks exist during the rest of the year, and thus fresh leaves are available throughout the year. Details on the study sites and distribution of the host plants have been described by Morishita and

Takafuji (1999a).

Field census for winter abundance and stage structure. Starting from 20 October 1998, we sampled at random 20–50 mite-damaged leaves each from *C. trichotomum*, *A. quinata* and peas for *T. kanzawai*, and peas and chrysanthemums for *T. urticae*. We counted separately the numbers of eggs, larvae plus nymphs, adult males and adult females of *T. kanzawai* or *T. urticae* to describe the seasonal change in abundance and stage structure throughout the winter. The census was conducted at approximately one-month intervals until mid-March, but no leaves were present on *C. trichotomum* after mid-January. Since the pea plants where *T. kanzawai* occurred had heavily deteriorated, the census was discontinued in mid-January.

Field-induced diapause rate. When adult females of the mites enter diapause, their body color turns vivid orange. However, even after diapause has terminated, the orange color is maintained until the temperature becomes favorable for reproductive activity. To monitor the proportion of diapause-induced females in the field, we discerned between females with orange color (in diapause) and those with a dark red color (*T. kanzawai* not in diapause) or those with a yellow-green color (*T. urticae* not in diapause) on the leaf samples described above. We considered that the orange-colored females had already entered diapause, though they may have already ended diapause. We also regarded the females with an in-between color to have entered diapause, as well. The females with this color included individuals with weak diapause and those that have ended diapause and resumed reproduction.

The capacity for diapause. In order to compare the inherent (genetic) capacity for diapause in the three *T. kanzawai* and the two *T. urticae* populations described earlier, we collected adult females from each host in early October, when diapause induction had not yet started in the field. We introduced 7–12 adult females of either species into each of 4 bean (*Phaseolus vulgaris*) leaves on water-saturated cotton in petri dishes (9 cm diameter and 2 cm depth). The 4 petri dishes were placed in a plastic container to maintain humidity. The females were allowed to oviposit for 2–4 days at 25°C 16L8D and removed. The eggs laid were then transferred to either 15, 18 or 20°C with a daylength of 9 h for diapause induction. The dia-

pause status of adult females was determined about one week after adult maturation on the basis of body color as described above. The bean leaves were not replaced with new ones during the experiment.

RESULTS

Winter ecology

Tetranychus kanzawai. Figure 1 (upper) shows that the population of *T. kanzawai* on *C. trichotomum* began to enter diapause earlier than the populations on two other hosts. In early November, about 20% of the females had entered diapause on *C. trichotomum*, whereas no induction had occurred on *A. quinata* and peas. The percentage of orange-colored females reached about 90% in early January both on *C. trichotomum* and pea. However, on *A. quinata* the maximum proportion of 48% was recorded in early December and thereafter the

proportion declined. Most females (>95%) from the three hosts, regardless of their body color, had already ended diapause in mid-January, as oviposition occurred within 3 days after they were transferred to 25°C 16L8D.

Both population densities on *C. trichotomum* and on pea continued to decline after October as the plants deteriorated, and in mid-January very few mites were observed on the remaining leaves (Fig. 2, upper). In particular, the population on *C. trichotomum* declined abruptly. The proportion of eggs and immatures became smaller after December in both populations (Fig. 3, left). Seventy to 80% of the mites surviving were adults. Thus, most of the eggs and immatures that failed to reach the adult stage on the plants by mid-winter died, due probably to starvation and/or cold. The dead eggs were shrunk and in such eggs the embryonic development was advanced. In addition, some adult females not in diapause left *C. trichotomum*, mov-

Fig. 1. Change in the percentage of orange-colored adult females in populations of *T. kanzawai* (upper) and *T. urticae* (lower) on different host plants.

Fig. 2. Change in the abundance (per damaged leaf; all stages inclusive) in populations of *T. kanzawai* (upper) and *T. urticae* (lower) on different host plants throughout the winter.

Fig. 3. Change in the stage structure in populations of *T. kanzawai* (left) and *T. urticae* (right) on different host plants throughout the winter.

ing to underground vegetation such as *Vicia angustifolia* L., as the plant deteriorated. This dispersal of non-diapause females may also have contributed to the lower proportion of eggs and immatures, as well as the low incidence of diapause on the plant.

On the other hand, the population on *A. quinata* maintained its abundance (Fig. 2, upper) and the stage structure remained rather constant throughout the winter (Fig. 3, left, bottom). Mortality of eggs and immatures was observed on the leaves, but the

very high proportions of eggs throughout the winter indicate that some eggs were newly produced and many of the new eggs survived the winter.

***Tetranychus urticae*.** The proportion of orange-colored females of *T. urticae* on both chrysanthemum and pea was much smaller than was that of *T. kanzawai* (Fig. 1, lower). The maximum proportions were only about 20% and 8% in populations on chrysanthemum and pea, respectively, which occurred in mid-February. Although the abundance

Fig. 4. Incidence of diapause at three temperatures with a daylength of 9 h in populations of *T. kanzawai* (upper) and *T. urticae* (lower) on different host plants.

on the two hosts declined during the mid-winter (Fig. 2, lower), both eggs and immatures were always present in high proportions throughout the winter (Fig. 3, right). Observations showed that the mortality rate of eggs and immatures seemed smaller in *T. urticae* than in *T. kanzawai*.

The capacity for diapause

In all three populations of *T. kanzawai* the diapause percentage decreased only slightly with increasing temperature, and even at 20°C more than 85% of the mites exhibited diapause (Fig. 4, upper). There were no significant differences in the diapause percentage among the populations at any temperature tested. Thus, these populations all had a genetically high capacity for diapause and there seemed to be no genetic diversification in diapause characteristics among them.

The two populations of *T. urticae* showed very low diapause percentages even at 15°C (Fig. 4, lower). The population on pea expressed nearly no diapause. The difference in diapause capacity between the two populations was consistent with the difference in field-induced diapause percentage.

DISCUSSION

The average daily ambient temperature in the

study area is between 6 and 10°C during the period from December to February. Thus, even in mid-winter, the temperature will often exceed the developmental zero (9–10°C) of the two species of mites (Osakabe, 1959; Ito, 1974) during the day, which will allow their development and reproduction. Winter cold and/or dryness will have more adverse effects on the survival of immatures, and eggs with advanced embryonic development, than on the survival of adults and new eggs, as suggested by direct observations of higher mortality in the former on host leaves. The high proportions of eggs and immatures of *T. kanzawai* on *A. quinata* and of *T. urticae* on chrysanthemum, both of which are good food resources during winter, indicate that the availability of food of good quality is essential for the survival of mites during winter unless they enter diapause.

The present diapause induction experiment showed that all three populations of *T. kanzawai* potentially have full capacity for diapause. The results also suggested that no genetic diversification in diapause capacity took place among the populations occurring on different hosts in this area, though genetic diversification is known in host preference or adaptability (Gomi and Gotoh, 1996; Gotoh et al., 1999). Nevertheless, the incidence of field-induced diapause was significantly lower in the *A. quinata* population. This lower incidence of diapause on the host suggests that the phenotypic expression and/or termination of diapause are largely dependent on food quality. This fact was experimentally shown in several tetranychid species such as *Panonychus ulmi* (Lees, 1953) and *Oligonychus ununguis* (Shinkaji, 1975). If the quality of hosts remains good during and after the diapause-induction period, mites may not express explicit diapause or they may end diapause more quickly.

In contrast to the field incidence of diapause in *T. kanzawai* in the present study, Morishita and Takafuji (1999b) reported that the incidence was about 60% at maximum for all three populations that occurred in late December. The discrepancy between the two studies is attributed to the different criteria with regard to diapause. In Morishita and Takafuji (1999b), the incidence of diapause is based on whether or not the females oviposit at 25°C under long daylength. On the other hand, in the present study the incidence is based on the

body color of the females. Both studies show that diapause ends before mid-winter, as was also reported by Mochizuki and Takafuji (1996). Thus, some of the orange-colored females had already terminated diapause in December and therefore the proportion of orange-colored females in the present study shows the cumulative percentage of the females that have already entered diapause, not the females that are currently in diapause. This early diapause termination before mid-winter is also known in some insects, although cold hardiness is maintained after diapause break (Danks, 1987; Goto et al., 1998).

T. urticae of Japan has wide genetic variation in diapause characteristics (Goka and Takafuji, 1990, 1991) and a wide host range (Yano et al., 1998), thereby enabling it to adapt to various environmental conditions. The populations of *T. urticae* in the present study area have a very weak diapause, as is known in most populations in warmer climates of Japan (Takafuji et al., 1991). In such areas the non-diapause character may provide the species with higher fitness than the diapause character (Tsuda et al., 1997). However, *T. urticae* is originally most common in cool climates, such as North America and northern Europe, and populations in these areas all have strong diapause (Veerman, 1985).

On the other hand, *T. kanzawai* is also distributed in the sub-tropics such as Taiwan and the tropics such as Thailand (Ehara, 1993). Although the distribution range of *T. kanzawai* has not been fully studied, the mites are likely to have originated from warmer areas than are *T. urticae* and therefore it may be reasonable that the former is less tolerant to winter cold than the latter. Thus, in non-warm areas a strong capacity for diapause should have been selected for *T. kanzawai* to survive the winter. The populations in southern areas such as Taiwan have a large variability in diapause capacity (A. Takafuji, unpublished), as have populations of *T. urticae* in southwestern Honshu. Thus, the different overwintering strategies of the two mite species may reflect differences in their original distribution range.

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